IBM T. J. Watson Research Center

Nanoelectronics Research Investment and the Future of Information Technology

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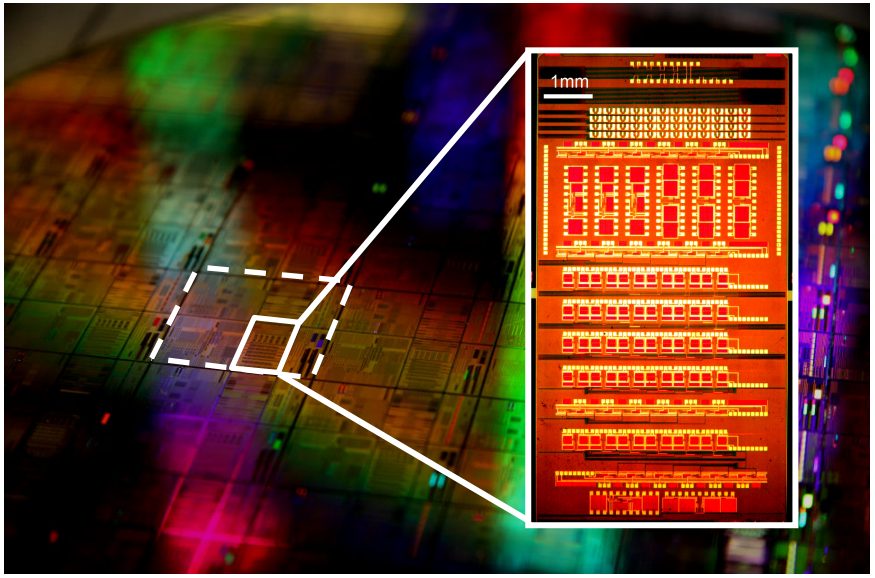
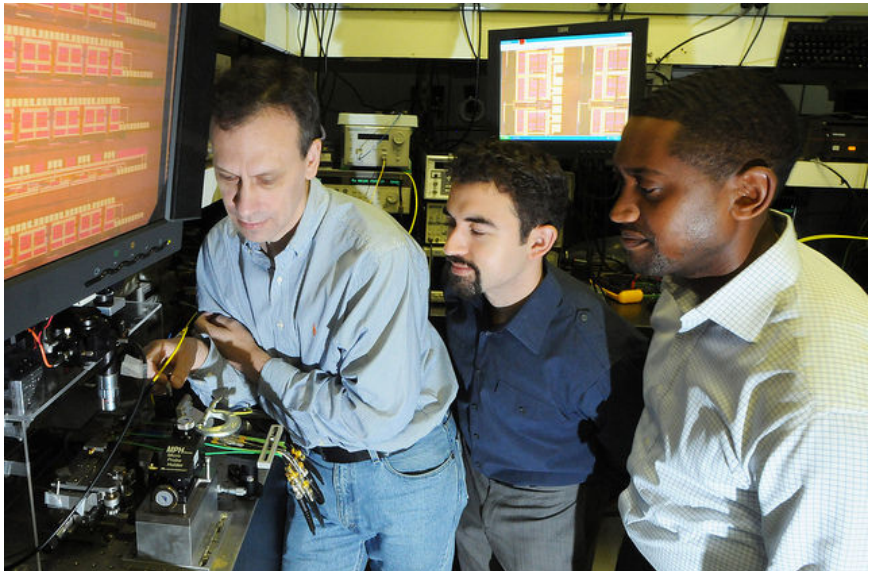
Made in IBM Labs: Breakthrough Chip Technology Lights the Path to Exascale Computing

Yorktown Heights, N.Y. - 01 Dec 2010: IBM scientists today unveiled a new chip technology that integrates electrical and optical devices on the same piece of silicon, enabling computer chips to communicate using pulses of light (instead of electrical signals), resulting in smaller, faster and more power-efficient chips than is possible with conventional technologies.

The new technology, called CMOS Integrated Silicon Nanophotonics, is the result of a decade of development at IBM's global Research laboratories…



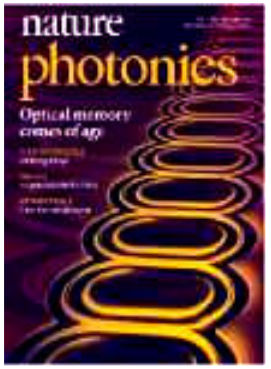


IBM Silicon Nanophotonics

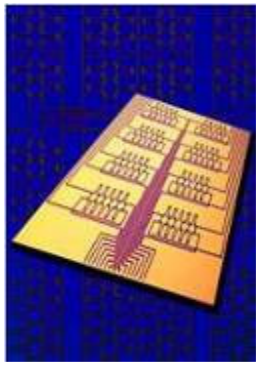
Scientific Impact (2003-2010)

2005
Slow Light

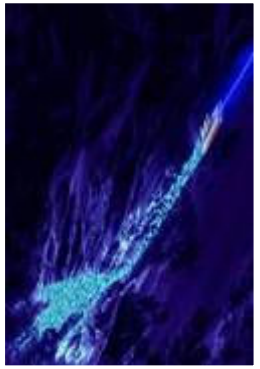
2006
Si Modulator



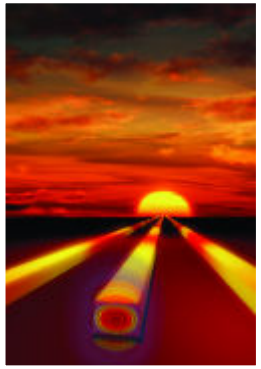
2007
Optical Buffer



2008
Si Switch



2009
APD Detector



2010
Amplifier

2010
Ge Receiver

Journal papers:	**>50**
Conferences:	**>150**
Citation index:	**>2,100**
Patents:	**>30**

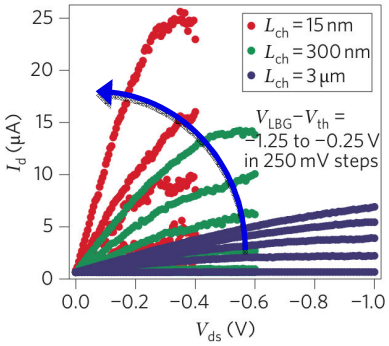
World-class scientific research lays the foundation for technology development!

Shrinking Carbon Nanotube Transistors

- Channel length
  - Scaled down to 15 nm (current Si technology is 30 nm)

Smaller channel gives:

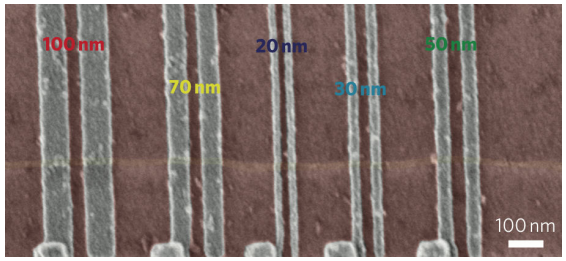
↑ Electrical current
@
↓ Applied Voltage

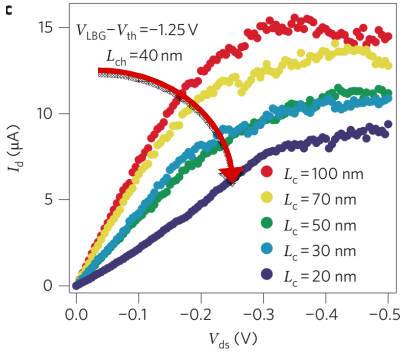


- Contact length
  - Scaled down to 20 nm (current Si technology is 40 nm)

Smaller contacts gives:

↓ Electrical current

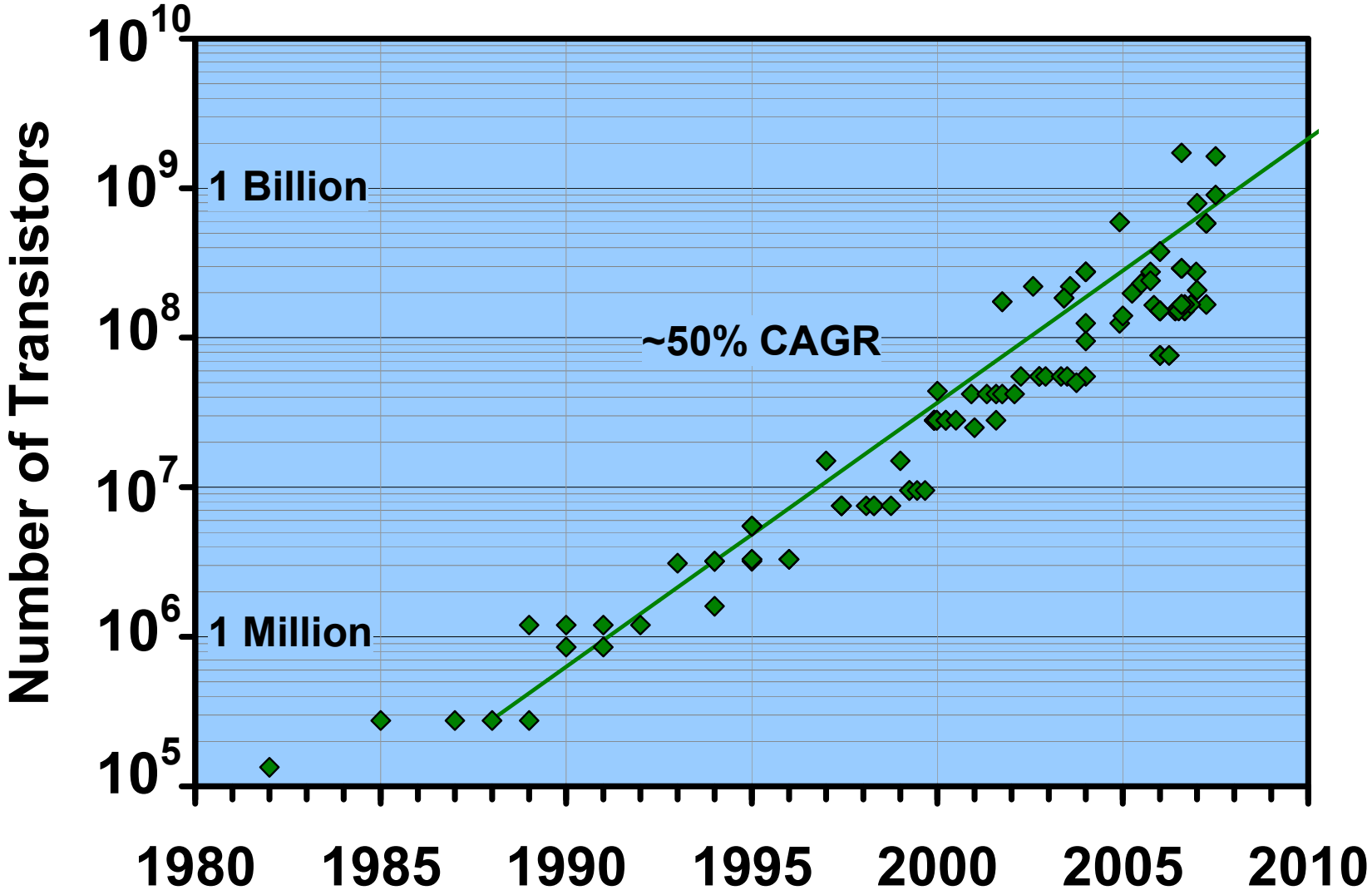




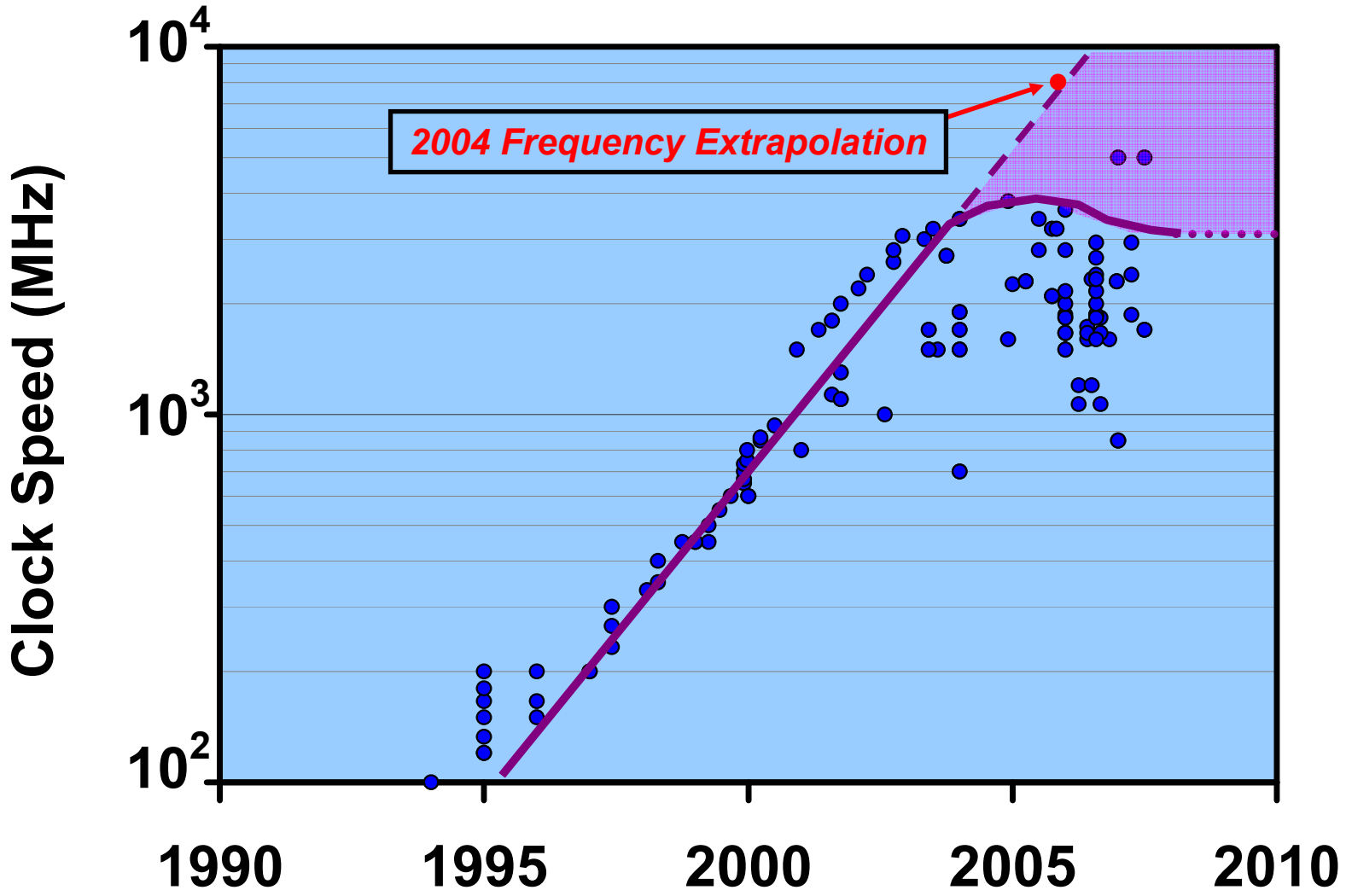
A. D. Franklin, *et al.*, *Nature Nanotechnol.* (2010).

Microprocessor Transistor Count

Full speed ahead.



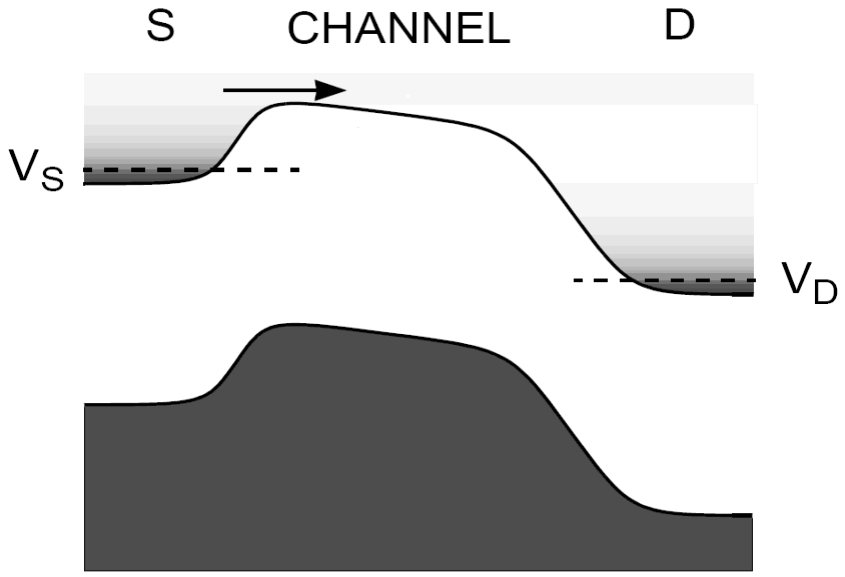
Microprocessor Clock Speeds



New device concepts are required for truly low-voltage or low-power digital logic.

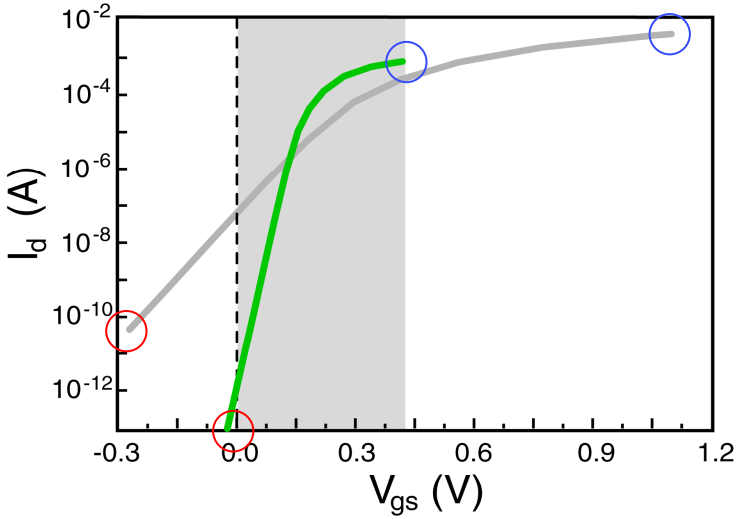
The energy dissipated by a field effect transistor in each switching operation is $\frac{1}{2}CV^2$

- To reduce C: Make the device smaller.
- To reduce V: Change the device physics!



Proposed Paths to Low-Voltage Switching

- Energy Filtering
  - The **Tunnel-FET** cuts off the high-energy tail of the Boltzmann distribution.
- Internal Voltage Step-up (Negative Capacitance)
  - The **Ferroelectric-Gate FET** allows a small gate voltage swing to produce a larger swing in ψ_s.
- Internal Transduction
  - The **Spin-FET** transduces a voltage to a spin state which is gated and then transduced back to a voltage state. The **NEMS switch** transduces a voltage to a mechanical state.



Nanoelectronics Research Initiative

Mission Statement

NRI Mission: Demonstrate novel computing devices capable of replacing the CMOS FET as a logic switch in the 2020 timeframe.

- These devices should **show significant advantage over ultimate FETs** in power, performance, density, and/or cost to enable the semiconductor industry to **extend the historical cost and performance trends** for information technology.
- To meet these goals, NRI pursues **five research vectors**, focused on discovering and demonstrating new devices and circuit elements for doing computation.
- Finally, it is desirable that these technologies be **capable of integrating with CMOS**, to allow exploitation of their potentially complementary functionality in heterogeneous systems and to enable a smooth transition to a new scaling path.

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Nanoelectronics Research Initiative Milestones

- 2001-2004: Defining Research Needs
  - ITRS-Emerging Research Device Technical Working Group
  - NSF-SRC Ind-Academia-Govt "Silicon Nanoelectronics and Beyond" Workshops
  - SIA Technology Strategy Committee workshops
  - ➢ *Defined 13 Research Vectors for finding the "next switch"*
  - ➢ *SIA Board passes resolution for formation of NRI*
- Current Member Companies:

AMD GLOBALFOUNDRIES IBM intel Texas Instruments Micron

- Sep 2005: First NRI and NRI-NSF Solicitations released
- Jan 2006: Research Programs started

NSF

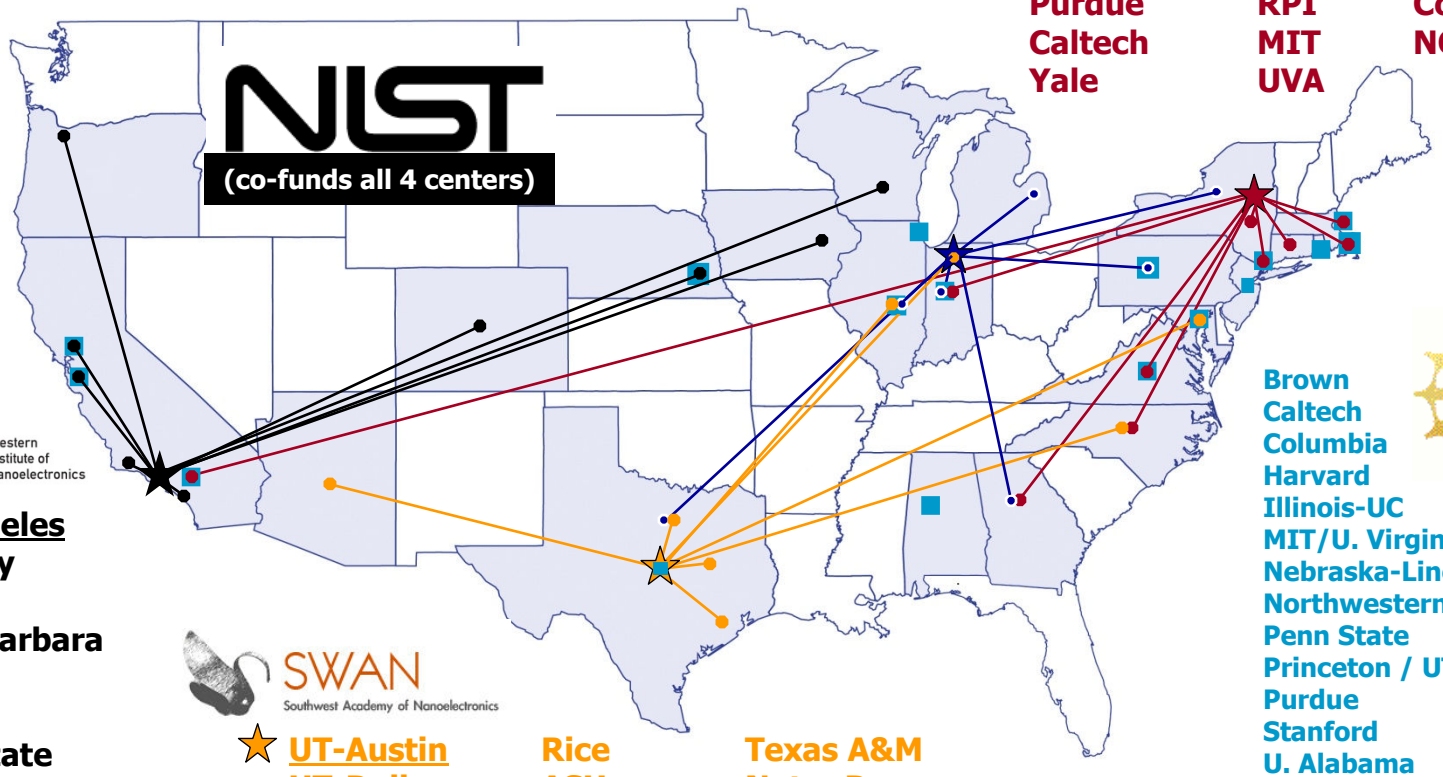
- Sep 2007: NIST joins NRI

NIST

- NRI partnership model highlighted as a sidebar in the National Nanotechnology Initiative (NNI) Strategic Plan (NNCO, 1/08)
  - Also called out in the House Appropriation Committee report (FY2008)
  - NRI showcased in Small Times' annual nanotechnology university issue

NRI Funded Universities

Finding the Next Switch



Nanoelectronics • Architectures MIND
MIDWEST INSTITUTE FOR NANOELECTRONICS DISCOVERY

★ **Notre Dame**
Illinois-UC
Michigan
Cornell
Purdue
Penn State
UT-Dallas
GIT

INDEX
INSTITUTE FOR NANOELECTRONICS DISCOVERY AND EXPLORATION

★ **SUNY-Albany**
Purdue
Caltech
Yale
GIT
RPI
MIT
UVA
Harvard
Columbia
NCSU

NIST
(co-funds all 4 centers)

WIN Western Institute of Nanoelectronics

★ **UC Los Angeles**
UC Berkeley
UC Irvine
UC Santa Barbara
Stanford
U. Denver
Portland State
U. Iowa
U. Nebraska-Lincoln
U. Wisconsin-Madison

SWAN Southwest Academy of Nanoelectronics

★ **UT-Austin**
UT-Dallas
U. Maryland
Rice
ASU
NCSU
Texas A&M
Notre Dame
Illinois UC

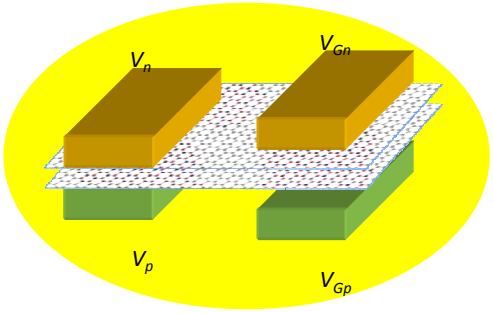
NSF

Brown
Caltech
Columbia
Harvard
Illinois-UC
MIT/U. Virginia
Nebraska-Lincoln
Northwestern
Penn State
Princeton / UT-Austin
Purdue
Stanford
U. Alabama
UC Berkeley
U. Maryland

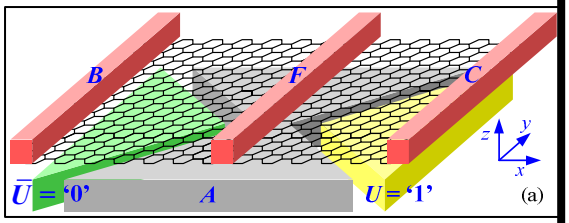
Over 35 Universities in 22 States

Some Post-CMOS Devices

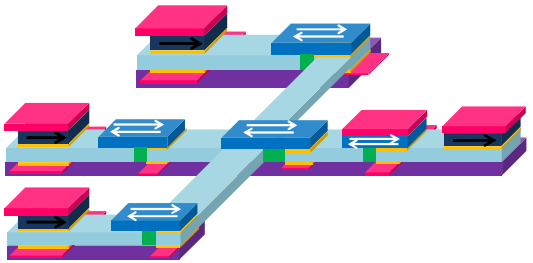
Graphene Bilayer pseudoSpin FET
UT Austin



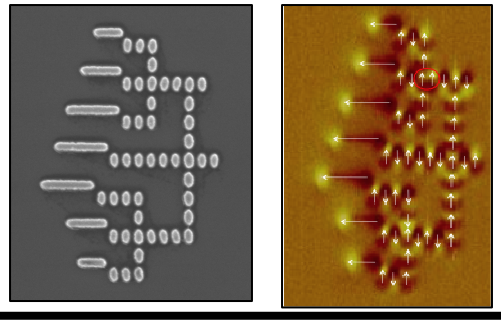
Graphene PN Junction
SUNY Albany



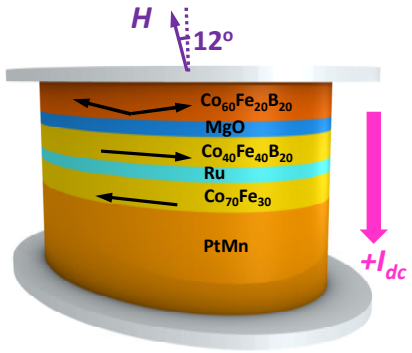
All-Spin Logic
Purdue U.



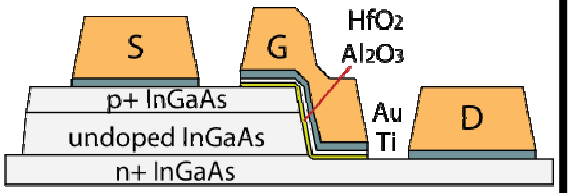
Nanomagnet Logic
Notre Dame, Berkeley



Spin-Torque Device
UCLA



Heterojunction TFET
Penn. State, Notre Dame



vertical TFET - side gated

NSF awards $24.5 million for center to stem increase of electronics power draw

http://www.berkeley.edu/news/media/releases/2010/02/23_nsf_award.shtml

Feb 23, 2010

The National Science Foundation has awarded $24.5 million to researchers at UC Berkeley, to head an ambitious, multi-institutional center that could one day lead to a million-fold reduction in power consumption by electronics. "Information processing consumes more and more energy as it becomes more intertwined with our lives," said Eli Yablonovitch, professor of electrical engineering and computer sciences and the director of the Center for Energy Efficient Electronics Science.

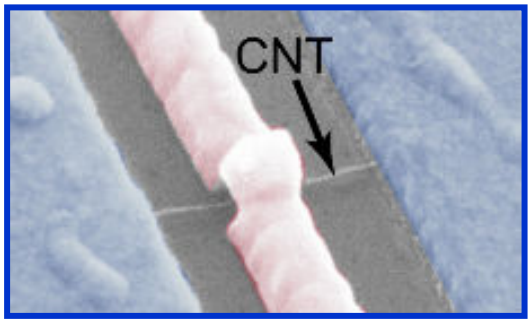
New Solicitation: Nanoelectronics for 2020 and Beyond

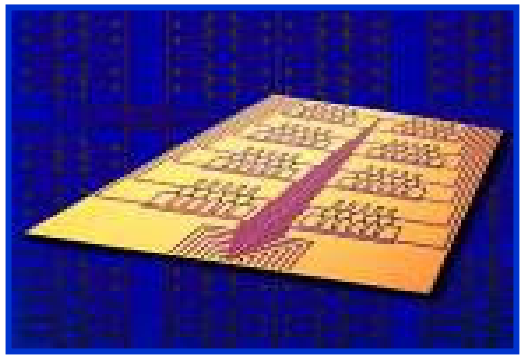
A Joint Activity between NSF and NRI

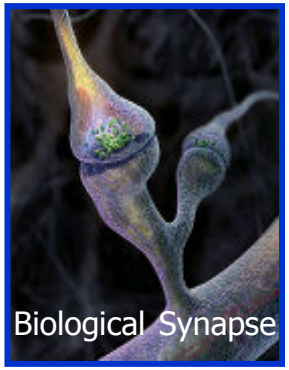
- The National Science Foundation (NSF), together with the semiconductor industry's Nanoelectronics Research Initiative (NRI) plan to jointly support innovative research and education activities on the topic of *Nanoelectronics for 2020 and Beyond.*
- Goal: Advance the forefront of computation, information processing, sensor technologies, and communications infrastructure beyond the physical and conceptual limitations of current technologies.
- Interdisciplinary research team awards.
- Proposals must address two of the following three areas:
  - *Exploring New Chemistries and Materials for Nanoelectronics*
  - *Exploring Alternative State Variables and Heterogeneous Integration for Nanoelectronic Devices and Systems*
  - *Exploring Novel Paradigms of Computing*

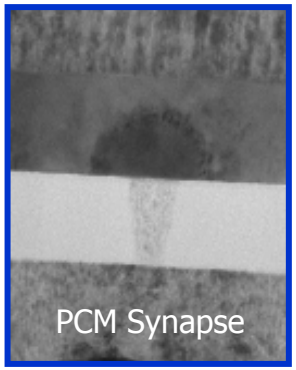
Research Challenges for 2020 and Beyond

- Discover and develop the “next switch.”
  - Carbon Electronics
  - Steep Subthreshold Slope Transistors
  - Spintronics
  - ?
- Explore new materials and device physics to break the memory bottleneck.
  - MRAM (Magnetic Random Access Memory)
  - PCM (Phase Change Memory)
  - ?
- Extend optical communication to the nanoscale.
  - Silicon Nanophotonics
  - Nanoplasmonics
  - ?
- Explore the fundamental physics of new information processing architectures.
  - Quantum Computing
  - Neuromorphic Systems and Synaptic Devices
  - ?



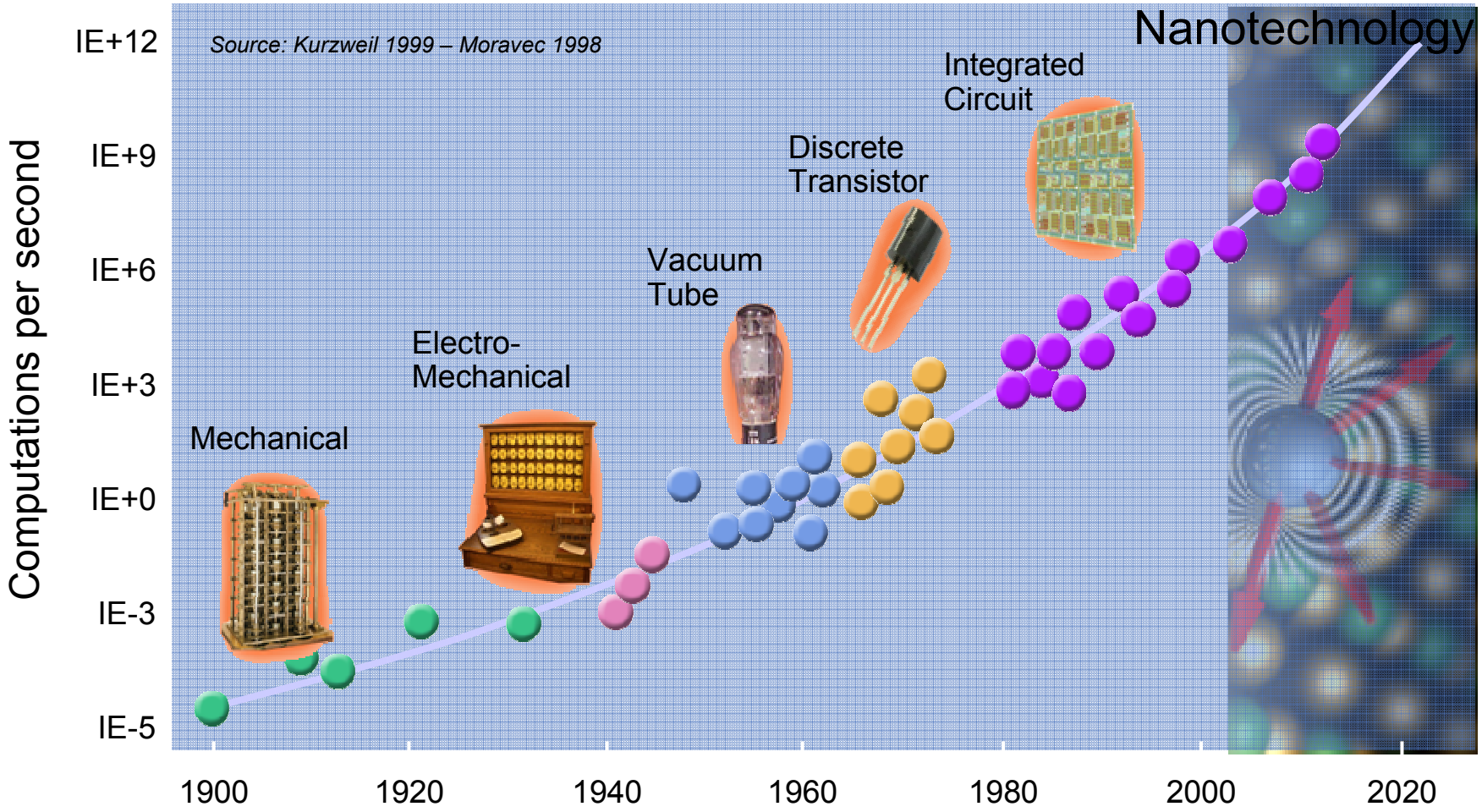






Goal: Continue the Curve . . .

$1000 Buys:



Thank you NSF!

Thank you DARPA!

Thank you NIST!

… and thank you NNI!